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Sustained Attention and Its Relationship to Fluid Intelligence and Working Memory in Children

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Abstract

Understanding individual differences in intelligence remains an interesting research question, even with more than a century of empirical research and large numbers of models and theories. We know that working memory (WM) is able to explain substantial amounts of variance in fluid intelligence in both children and adults, but we also know that it is not the only predictor of intelligence. There are many other information-processing mechanisms that have been studied. Results in adult samples seem to indicate that sustained attention—the ability to maintain attention on a specific task over an extended period of time—is strongly related to fluid intelligence. There is little research on this topic in childhood, but the available data seems to converge with results from adult samples. The aim of the present study was to assess sustained attention and its relationship to fluid intelligence and WM in children. Additionally, we wanted to explore whether sustained attention contributes to the prediction of intelligence over and above WM. A sample of 125 ten-year olds was assessed using tests of fluid intelligence, sustained attention and WM. The results showed that, as expected, WM and fluid intelligence were significantly related. Surprisingly however, sustained attention was not related to fluid intelligence or WM. Using results from previous studies and theoretical considerations, we concluded that sustained attention may not be directly related to fluid intelligence in childhood, but rather that it may be a more distal factor influencing information processing in more unstructured learning situations and hence impacting academic achievement.

Keywords: sustained attention, fluid intelligence, working memory, childhood

1. Introduction

Understanding individual differences in intelligence remains an interesting research question, even with more than a century of empirical research and large numbers of models and theories in adulthood and childhood. We know that working memory (WM) is able to explain substantial amounts of variance in psychometric intelligence in both children and adults , but the results as to the magnitude of the relationship between WM and intelligence are ambiguous. While some have found correlation coefficients of up to $r = .9$ between intelligence and WM (e.g., Kyllonen & Christal, 1990), others argue that the relationship is much smaller (e.g., Ackerman, Beier, & Boyle, 2005). What is clear, is that WM is not the only predictor of intelligence and that there are other information-processing mechanisms that can explain variance in intelligence. Studies have for example shown that processing speed (Coyle, 2013; Coyle, Pillow, Snyder, & Kochunov, 2011; Fry & Hale, 2000; Kail, 2007) and sensory discrimination are also significantly related to intelligence (Deary, Bell P., Bell A., Campbell, & Fazal, 2004; Demetriou, Mouyi, & Spanoudis, 2008; Troche & Rammsayer, 2009).

Another information-processing mechanism that may be related to psychometric intelligence and which is the focus of the current study, is sustained attention. Sustained attention is considered to be the ability to maintain attention on a specific task over an extended period of time (Betts, McKay, Maruff, & Anderson, 2007; Coull, 1998). It is often suggested that sustained attention is related to psychometric intelligence (e.g., Schweizer, 2005), which makes sense intuitively. Research with adults has provided support for this assumption (see e.g., Burns, Nettelbeck, & McPherson, 2009; Ren, Schweizer, & Xu, 2013; Schweizer & Moosbrugger, 2004), but there is very little evidence in research with children (see Tillman, Bohlin, Sorensen, & Lundervold, 2009). The aim of the present study was to explore the relationship between sustained attention and fluid intelligence as well as WM in children. Furthermore, we wanted to assess whether sustained attention contributes to the prediction of intelligence in childhood over and above WM.

1.1 Definition of Key Concepts

Over the last 100 years there has been a lot of research on the how and what of intelligence. Recent models describe individual differences in intelligence with a fairly small number of dimensions of mental ability, referred to as factors, including for example, verbal ability and visuo-spatial reasoning (Hunt, 2011). For the present study we focused on fluid intelligence as a measure of intelligence, which is a prominent factor in most models of psychometric intelligence. Fluid intelligence is generally describes as the ability to flexibly adapt one's thinking to new problems and situations (e.g., Cattell, 1963) and it is considered to be a good measure of general intelligence (see e.g., Burns et al., 2009). Additionally, tests of fluid intelligence are deemed to be relatively culture free and do not place emphasis on language (e.g., Hunt, 2011; Willis, Dumont, & Kaufman, 2011).

Working memory is, just like intelligence, a complex construct. As of yet, there is not one, well-agreed on definition of WM. While there is much disagreement as to the exact structure and functioning of WM, most researchers agree that it is a limited-capacity system responsible for the maintenance of information and the simultaneous manipulation of such information over short periods of time (see e.g., Conway, Getz, Macnamara, & Engel de Abreu, 2011). Research has shown that WM plays an important role in many cognitive tasks, including language learning, reading, mathematics, and problem solving (e.g., Cowan & Alloway, 2009; Henry, 2012). WM is typically measured using complex span tasks. In complex span tasks participants are required to hold a piece of information in mind while manipulating or processing the same or different information (Conway et al., 2005). They are considered to represent WM as a multi-faceted system that captures variance from different processes subsumed under WM, such as short-term capacity and attention control (Unsworth, Fukuda, Awh, & Vogel, 2014).

Sustained attention is generally described as the ability to maintain attention on a specific task over an extended period of time. In task that measure sustained attention, resources are continuously allocated to detect rare and unpredictable events (Betts et al., 2007; Coull, 1998). There are various ways to assess sustained attention. In studies with children, so-called Continuous Performance Tasks (CPTs) have a long history of being used to measure sustained attention and are still commonly used today (Conners, Epstein, Angold, & Klaric, 2003; Steele, Karmiloff-Smith, Cornish, & Scerif, 2012).

1.2 Relationship between the Constructs

There is ample research to show that fluid intelligence and WM are substantially related in both adults (e.g., Ackerman et al., 2005; Conway et al., 2011) and children (e.g., Engel de Abreu, Conway, & Gathercole, 2010; Giofrè, Mammarella, & Cornoldi, 2013; Hornung, Brunner, Reuter, & Martin, 2011). There is much less empirical research addressing the relationship between sustained attention and intelligence as well as the relationship between sustained attention and WM. Research with adults has shown that intelligence and sustained attention are significantly related (Burns et al., 2009; Ren et al., 2013; Schweizer & Moosbrugger, 2004; Schweizer, Zimmermann, & Koch, 2000), and there are also results showing that sustained attention and WM are related in adults (Burns et al., 2009). There is very little research on the relationship between intelligence or WM and sustained attention in childhood (Tillman et al., 2009), but there are some results indicating a small but significant relationship between sustained attention and fluid intelligence, as well as between WM and sustained attention (Tillman et al., 2009).

Taking a closer look at research on sustained attention, there seem to be two ways in which sustained attention is assessed. There are tasks that demand performance to be maintained for extended periods of time, but that do not explicitly demand speeded performance (e.g., CPTs). Then there are tasks that measure sustained attention with a demand for rapid performance under time constraint (i.e., so-called cancellation tasks) or other cognitive demands (Burns et al., 2009; Tillman et al., 2009). It seems that many of the studies that find an association between intelligence and sustained attention use tasks of the latter category (e.g., Buehner, Krumm, Ziegler, & Pluecken, 2006; Ren et al., 2013; Schweizer & Moosbrugger, 2004; Schweizer et al., 2000). There is some reservation towards using such tasks as measures of sustained attention, mainly because they may also have substantial cognitive demands (e.g., on WM) or significantly overlap with processing speed (see Burns et al., 2009; Tillman et al., 2009). To avoid these issues in the present study and because of the aforementioned common use of CPTs in studies with children, we decided to focus on CPTs as measures of sustained attention here.

2. Method

2.1 Participants

The sample consisted of 120 children (54% boys) ranging in age from 9 years 9 months to 11 years 9 months (mean age: 10.58 years, SD = .43 months). The children were recruited through public schools in Switzerland. The study was approved by the local ethics committee and informed consent was obtained from all parents.

2.2 Tasks

2.2.1 Assessment of Fluid Intelligence

Fluid intelligence was measured using the short version of the CFT 20-R (Weiss, 2006; reliability: .92). The CFT 20-R is an adapted and revised version of Cattell's Culture Fair Intelligence Test. It consists of four subtests: Series Completion, Classification (odd elements), Matrix Completion, and Topological Reasoning (dot task). The dependent measure used for this task was the number of correctly answered items in the four subtests.

2.2.2 Assessment of Working Memory

Participants completed a translated and adapted version of the listening recall task from the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001) and the letter-number-sequencing task from the German version of the Wechsler Intelligence Scale for Children (Petermann & Petermann, 2008).

Listening Recall (LR): In this task, participants heard a series of simple sentences (e.g., "lions have four legs", "cows can fly") and were asked to judge whether each sentence made sense or not and to simultaneously remember the last word of each sentence. At the end of each trial, participants were asked to recall the last word from each sentence in the order presented. There were 6 trials for each span length. When 4 out of the 6 trials were answered incorrectly, the task was terminated; otherwise the length of the sequence was increased by one sentence. The total number of correctly answered trials (correct recall of the last word of each sentence) was used as the dependent variable.

Letter-Number Sequencing (LNS): In this task, children heard a mixed sequence of letters and digits. They were required to repeat the letters and numbers, beginning with the numbers in numerical order followed by the letters in alphabetical order. The task was conducted according to the instructions in the test manual (see Petermann & Petermann, 2008). The total number of correctly answered trials (correctly recalled number-letter-sequences) was used as a measure of performance.

2.2.3 Assessment of Sustained Attention

We used three continuous performance tasks to assess sustained attention. For all three tasks, a composite score calculated using latency (reaction times; RT) and variability of response (standard deviation of RT) was used as the indicator of performance (see e.g., Betts et al., 2007).

CPT-AX: This task was an adapted version of the CPT-AX task. Instead of responding to the critical combination of the letters A and X, the children were asked to respond to the cue-target combination of pictures (shark and worried diver), while ignoring distractors (perceptually similar to the cue), non-cued targets (worried diver without a shark preceding it) and non-targets (happy diver). There were 150 trials, of which 30 (20%) were critical cue-target combinations. Within a trial the Interstimulus Interval (ISI), varying randomly between 1500ms and 1900ms, was followed by the stimulus presentation lasting 700ms.

CPT-X: This task was an adapted version of the CPT-X task. Instead of responding to the letter X, children were asked to respond to a picture of a grey fish while ignoring the distractors (coloured fish). There were 150 trials, of which 15 (10%) were targets. Within a trial, an ISI, varying randomly between 1100ms-1500ms, was followed by the presentation of the stimulus (duration: 400ms).

CPT-NotX: This task was an adapted version of the CPT-NotX task. Children were asked to press a button for all distractor items (different types of fruit) but not for the target (picture of a lemon). There were 150 trials, of which 15 (10%) were targets. Within a trial, an ISI varying randomly between 1100ms-1500ms was followed by the presentation of the stimulus for 400ms.

2.3 Procedure

Children were tested three times over the course of 3 days to two weeks during school hours. In one of these sessions the CFT 20-R was administered in a small group setting. Testing of both sustained attention and working memory was split into two sessions. The order of tasks was randomized across and in-between sessions, with working memory tasks and sustained attention tasks appearing in each of the two sessions.

2.4 Statistical Analyses

Structural equation modelling (SEM) was performed using AMOS22 software (Arbuckle, 2006). Model fits were considered good when the chi-square probability was greater than .5, the Comparative Fit Index (CFI) was greater than .95, the Root-Mean-Square (RMSEA) smaller or equal to .06, the Standardized Root Mean Square Residual (SRMR) smaller than .10, and the normed χ^2 below 2 (Garson, 2012; Kline, 2011). We did not include accuracy measures from the sustained attention tasks, because the accuracy for both CPT-AX and CPT-X was very high (94.46% and 98.73% respectively) indicating ceiling effects for accuracy in these measures.

3. Results

Descriptive statistics for all variables included in the study are shown in Table 1. To test the assumption that the four subtests of the CFT 20-R could be added to form one score, we performed a Principle Component Analysis (PCA) with oblique rotation (oblimin). The results showed that all four subtests loaded onto one factor [KMO = .62; Bartlett's test of sphericity χ^2 (6) = 36.49, $p < .001$], indicating that this assumption was correct. We computed a composite score using all four subtests to represent fluid intelligence in the following Pearson correlations.

Pearson correlations for all tasks included in the study are presented in Table 2. The results showed that the WM tasks were significantly related to each other and that the sustained attention measures were significantly related to each other. While the WM tasks were also significantly related to fluid intelligence, none of the sustained attention measures were related to either WM or fluid intelligence.

Table 1. Descriptive statistics for age and all variables included in the study

Variable	*M (SD)*	Range
Age (in years)	10.63 (.54)	9.56-12.66
CFT 1 (Series Completion)	10.11 (2.26)	2-15
CFT 2 (Classification)	7.43 (2.04)	3-13
CFT 3 (Matrix Completion)	8.92 (2.17)	2-13
CFT 4 (Topological Reasoning)	4.7 (1.79)	1-9
Listening Recall	14.8 (2.80)	7-23
Letter-Number-Sequencing	17.28 (2.05)	13-23
CPT-AX (RT)	509.49 (83.79)	374.23-771.48
CPT-AX (Variability)	155.69 (70.37)	60.96-429.57
CPT-X (RT)	427.14 (48.14)	256.13-591.13
CPT-X (Variability)	90.93 (47.82)	28.67-266.67
CPT-NotX (RT)	336.41 (45.47)	234.16-474.49
CPT-NotX (Variability)	109.99 (37.33)	64.43-262.72

Table 2. Pearson correlations between fluid intelligence, WM tasks, and sustained attention tasks

	1.	2.	3.	4.	5.	6.
1. fluid intelligence	-	**.31**	**.37**	-.01	-.01	-.08
2. Listening Recall		-	**.46**	-.10	-.08	-.07
3. Letter-Number-Sequencing			-	.03	.13	-.01
4. CPT-AX				-	**.41**	**.24**
5. CPT-NotX					-	**.18**
6. CPT-X						-

Note. Correlations printed in bold are significant at $p < .05$.

In a next step, we used SEM to assess the relationship between the constructs. We wanted to make sure that small but significant relations between sustained attention and WM or fluid intelligence were not masked by task specific issues. The use of SEM allows task specific variance to be controlled for, measurement errors to be minimized, and common features of tasks to be pronounced. This leads to more precise assessment of the relations among assessed constructs.

We tested a model assuming that both WM and sustained attention predict distinct portions of variance in fluid intelligence. Regression coefficients were computed from WM onto fluid intelligence and from sustained attention onto fluid intelligence, while sustained attention and WM were assumed to correlate. Age was used as a control variable, correlating with sustained attention and WM and regressing onto fluid intelligence (see Figure 1). The model yielded a good model fit [$\chi^2(30) = 32.97$, $p = .324$, normed $\chi^2 = 1.1$; CFI = .97; RMSEA = .03; SRMR = .06] and all factor loadings on the latent variables were significant at $p < .05$. Age was not significantly related to WM, sustained attention, and fluid intelligence. As expected, WM significantly predicted fluid intelligence. Sustained attention could not predict variance in fluid intelligence. Furthermore, WM and sustained attention were not correlated.

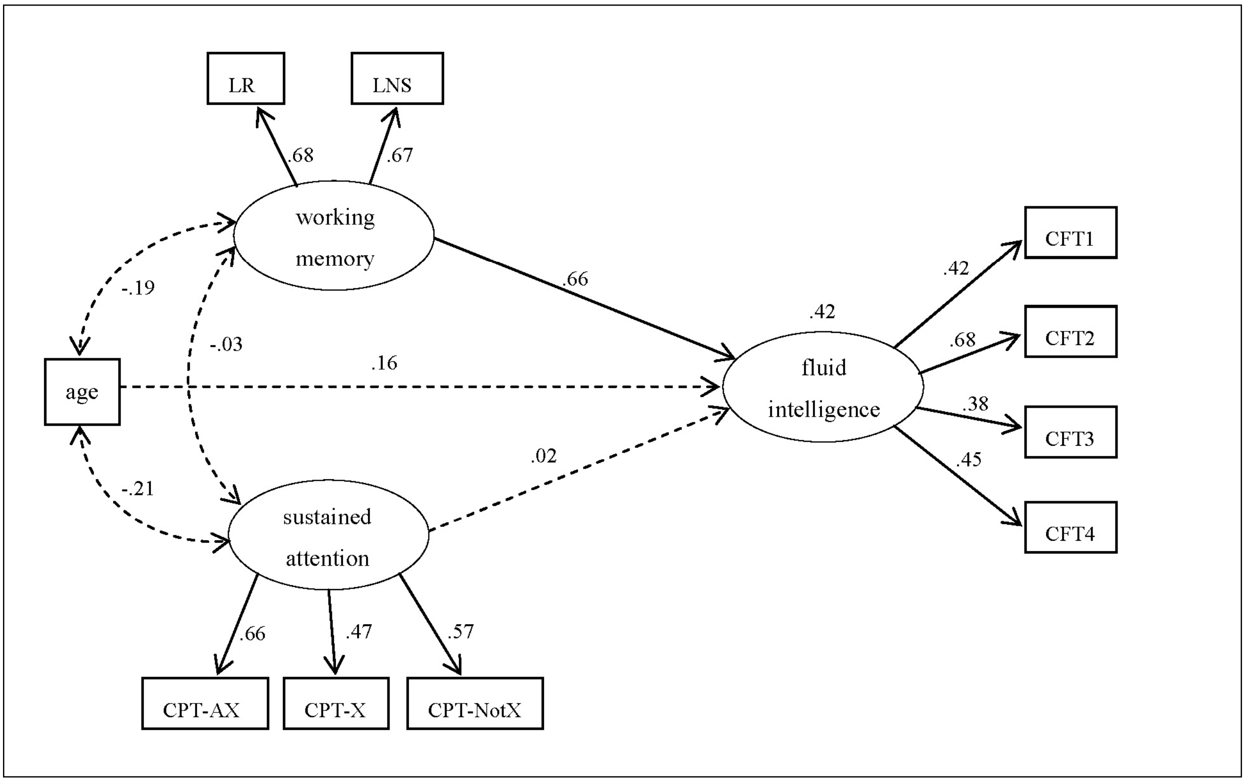

Figure 1. Structural equation model testing the relationship between sustained attention, WM and fluid intelligence. Dashed lines represent non-significant paths

4. Discussion

The aim of the present study was to assess whether sustained attention contributes to the prediction of intelligence over and above WM in children. The results showed that while WM and fluid intelligence were significantly related as expected, sustained attention was not related to either fluid intelligence or WM.

The finding that sustained attention was not related to fluid intelligence or WM was surprising. From results of previous studies (Burns et al., 2009; Tillman et al., 2009) we had expected significant (if not strong) correlations between sustained attention and fluid intelligence as well as WM. There are a number of possibilities that may explain why our results differ from previous studies. Firstly, it is possible that sustained attention and fluid intelligence become more related with development, and that while these two aspects may not be (strongly) related in children, they may be strongly related in adults. Secondly, it is also possible that the differences between our results and the results of previous studies are due to the type of sustained attention tasks used. Like Tillman et al. (2009) we used CPTs to measure sustained attention. However, while Tillman et al. used the traditional CPT-X task with letters, we used adapted versions with pictures as stimuli, which may have influenced the cognitive load of the tasks. It is possible that the use of pictures instead of letters reduced the cognitive load in this age group, resulting in a purer measure of sustained attention and thus differing results. A further reason for our results could be the age group studied and the fact that our measures of sustained attention were speed-based. Using reaction times as a measure of performance means that processing speed is always inherently involved. Recently, Demetriou et al. (2013) showed that while processing speed is related to intelligence, the strength of the relationship varies with age. They found that speed and intelligence were strongly related at ages 6-8 and 11-13, but no so at ages 4-7 and 9-11. As the majority of our sample falls into the 9-11 age range, the relationship between speed and intelligence would be expected to be on the low side. This could partly explain the very low correlations between sustained attention and fluid intelligence in the present study. It is possible that if we had studied a different age range, the relationship may have been closer and would have confirmed previously reported results. However, it could then be argued that the statistical relationship between the two constructs is not necessarily due to an actual relationship, but is indeed just due to the underlying relationship between processing speed and intelligence. Future studies should therefore include both attentional but also speed measures when exploring individual differences in intelligence.

While there is a distinct lack of studies on the relationship between sustained attention and fluid intelligence in children, studies looking at the relationship between academic achievement and sustained attention may be informative in this context (Steele et al., 2012; Steinmayr, Ziegler, & Träuble, 2010). These studies find that sustained attention is significantly related to academic achievement when it is measured later in time. Steinmayr and colleagues (2010) showed that sustained attention is able to moderate the relationship between intelligence and school achievement in adolescents, when school achievement is measured 5 months later. Steele et al. (2012) were able to show that sustained attention did not predict numeracy when measured concurrently in children aged between 3 and 6 years, but did predict numeracy performance one year later. These studies indicate that sustained attention is at the very least involved in academic achievement and learning. It is possible that sustained attention is relevant in more unstructured learning situations and less so in highly structured situations, such as filling out an IQ test. It is possible that sustained attention is not relevant to fluid intelligence per se (as reflected in our results), but that sustained attention and fluid intelligence are both involved in scholastic achievement. It is also possible that better sustained attention helps children to better use their cognitive potential (i.e., intelligence) to achieve in academic tasks. These speculations are, to a certain extent in line with previously voiced theoretical considerations. Steele et al. (2012) for example, explain that sustained attention may be important, not for using knowledge or cognitive ability in a certain situation, but for learning and acquiring knowledge (i.e., establishing and consolidating representations over time). This resonates with the present findings, where performance in WM is related to the online (concurrent) performance in fluid intelligence tasks, but sustained attention measures are not. Unfortunately we are unable to test the hypothesis put forward by Steele et al. (2012) with our data.

4.1 Limitations

There are some limitations to the present study that deserve to be mentioned. Firstly, our measures of sustained attention were on the short side of CPTs in terms of time to complete. We wanted to make sure we were measuring a child's ability to sustain attention over a longer period of time and not motivational aspects of task completion. While these two aspects are hard to separate (if this is even possible), we considered that a longer task completion time would not increase the quality of our data. In deciding on the length of time for the CPT tasks we followed Steele et al.'s (2012) and Betts et al.'s (2007) example. Secondly, we only focused on fluid intelligence. In relation to the other studies in this area, it would have been interesting to expand our tasks to include general intelligence as well as academic achievement. Furthermore and looking at the results by Steinmayr et al. (2010) and Steele et al. (2012) it would have been informative to use a longitudinal design.

4.2 Conclusion

The aim of the present study was to assess the relationship between sustained attention, fluid intelligence, and WM in children. We found that, as expected, WM and fluid intelligence were significantly related. Surprisingly, sustained attention was not directly related to either fluid intelligence or WM. Theoretical considerations and research from related areas indicate that these results make sense, meaning that sustained attention may not be directly related to intelligence, but rather that sustained attention may be a more distal factor influencing information processing in more unstructured learning situations hence impacting academic achievement.

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